Effect of Pulsed or Continuous Delivery of Salt on Sensory Perception Over Short Time Intervals

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Abstract

Salt in the human diet is a major risk factor for hypertension and many countries have set targets to reduce salt consumption. Technological solutions are being sought to lower the salt content of processed foods without altering their taste. In this study, the approach was to deliver salt solutions in pulses of different concentrations to determine whether a pulsed delivery profile affected sensory perception of salt. Nine different salt profiles were delivered by a Dynataste device and a trained panel assessed their saltiness using Time-Intensity and single score sensory techniques. The profile duration (15 s) was designed to match eating conditions and the effects of intensity and duration of the pulses on sensory perception were investigated. Sensory results from the profiles delivered in either water or in a bouillon base were not statistically different. Maximum perceived salt intensities and the area under the Time-Intensity curves correlated well with the overall perceived saltiness intensity despite the stimulus being delivered as several pulses. The Overall Saltiness Scores for profiles delivering the same overall amount of sodium were statistically not different from one another suggesting that, in this system, pulsed delivery did not enhance salt perception but the overall amount of salt delivered in each profile did affect sensory perception.

Keywords: Dynataste, Sensory perception, Sodium chloride, Time-intensity,

Introduction

To meet the salt consumption targets set by various Food Regulatory Bodies (and therefore decrease the incidence of hypertension and other salt-related issues), processed foods are a focus as they contribute a significant proportion of dietary salt intake and this intake is not under the direct control of the consumer. In the UK, processed foods are responsible for about 80% of salt intake (Angus, 2007) and the food industry has responded by reducing the amount of salt in its products since 2004 (UK Food Standards Agency, 2008). To meet the revised, more stringent target of 6 g salt per day, further reductions are needed and, often, the determining factor is that the product's flavor becomes unacceptable once a certain salt level has been reached. One approach to salt reduction is to deliver salt in such a way that it maximizes the perception of saltiness. The use of salt in different particle sizes, which results in controlled delivery to the taste buds, has been proposed as a means of enhancing salt perception in low water foods (Dubois & Tsau, 1992). In this paper, the controlled delivery of salt solutions using different concentration-time profiles was studied over a time-scale related to food consumption.

There is evidence that taste perception is a time dependent event (McBurney, 1976). One well-documented example is adaptation (Abrahams et al., 1937; Ganzevles & Kroeze, 1987; Meiselman & Buffington, 1980). It occurs when a taste stimulus is continuously applied to the tongue and results in the gradual decline of taste sensitivity. The extent of taste sensitivity decline as a function of stimulus concentration or stimulation method has been extensively studied (Bujas et al., 1995; Meiselman & Buffington, 1980; Neyraud et al., 2003) but it has long been accepted that, under normal eating or drinking conditions, adaptation is very limited (Moskowitz, 1978; Theunissen et al., 2000) and this has been attributed to mouth movements and swallowing, disrupting the process of adaptation (Theunissen & Kroeze, 1996). In a similar fashion, delivery of solutions of taste stimuli in the form of pulses of different concentrations and duration have been shown to disrupt adaptation (Halpern & Meiselman, 1980; McBurney, 1976). Pulses of several seconds duration have been reported to, not only disrupt adaptation but also, to enhance salt perception (Meiselman & Halpern, 1973) over 60 seconds periods. However, 60 seconds is a relatively long period for a normal eating experience and the aim of this paper was to check whether pulses could be used to enhance salt perception over shorter time intervals.

In this study, tastants were delivered using the Dynataste system (Hort & Hollowood, 2004) which, because of its continuous solution delivery, simulates a real eating experience and minimizes taste adaptation effects. The time scale chosen was 15 seconds which approximates to the time a "mouthful" of food is resident in mouth. Sensory evaluation studied the effect of delivery profile on saltiness using salt solutions and salt in a bouillon system, as salt can also deliver a cross modal effect with many savory flavors. If delivery profiles can affect saltiness perception, then the optimum profiles could be used to design specialized food microstructures to deliver salt to elicit the best taste properties for the minimum consumption. The aim was to ascertain whether the delivery profile affected perception of saltiness and might be used to decrease salt content in products like soups and sauces while maintaining the characteristic flavor of the food.

Material and methods

Dynataste

Dynataste is a multichannel delivery system for solutions, based on a series of pumps which can be programmed to deliver different profiles while maintaining a constant flow rate (Hort & Hollowood, 2004). The flow rate used for all experiments was 10 mL/min and solutions were delivered at ambient temperature (18-21 ^{o}C). A 1.75 m long piece of Teflon tubing (internal diameter: 0.1778 mm) brought the delivered solution from the Dynataste to the sensory booth where the panelist was located so that the panelists were unaware of Dynataste operation. The profile of the solution delivered at the end of the tube was compared to that programmed into the pumps using sodium specific electrodes (Microelectrodes, Inc., Bedford, USA). Each profile was monitored in triplicate for sodium content and volume delivered. The length of the pulses recorded as well as both the volumes and overall amounts of sodium delivered were consistent with the theoretical profiles (theoretical sodium delivered *vs*. actual sodium delivered r^2=0.96). A delay of 2 to 3 s was recorded between the start of the pumps and the delivery of the first drops to the panelists and each profile was shifted by 3 s to take this into account.

Sensory testing

Full approval from the local Ethics Committee was obtained before the study commenced. Eleven panelists (9 women, 2 men, aged 46 to 69), experienced in sensory testing, were given training in ranking and rating salt solutions using aqueous solutions of five different salt concentrations (0.79, 1.73, 2.52, 3.93 and 4.32 g Na/L) presented in 45 mL plastic cups. Although these panelists had extensive experience using the Dynataste system, further training was carried out using three different salt profiles (A, C and I; see Table 1) from which Time-Intensity measurements and Overall Saltiness Scores were obtained. After training, all the panelists' results in terms of Overall Saltiness Score (OSS), Area Under the Curve (AUC) and maximum intensity (Imax) were consistent with the overall amount of salt delivered. Between profiles, panelists were provided with water (Evian, Danone, France) and unsalted crackers (99% Fat Free, Rakusen's, UK) to cleanse their palates. The order of presentation was randomized for each test for each assessor. The samples were coded with three digit numbers. During the assessment of saltiness, reference samples in 45 mL cups were available at all times. A saltiness reference of 100 corresponded to a sodium concentration of 3.93 g Na/L (equivalent to 10 g/L NaCl). The reference samples were given in water for the "salt in water" study and in bouillon for the "salt in bouillon" study. For the "salt in bouillon" experiments, an additional reference sample corresponding to a score of 20 (0.79 g Na/L; equivalent to 2.0 g/L NaCl) was provided.

Samples

Nine profiles were chosen to investigate the effect of pulse length (comparison of profiles C and D; E, F and G), pulse concentration (comparison of profiles A and B; C and H) and final concentration (comparison of profiles F and G) on salt perception (Table 1). Six of these profiles were also delivered in a bouillon base. Fifteen second profiles were used as a compromise between a realistic eating experience and a minimum time required to perform Time-Intensity measurements. An identical initial sodium concentration was chosen for all the profiles (0.79g Na/L) in order to avoid the contrast between the absence of salt (Na concentration below that of saliva) and salt being delivered as this effect was not the focus of this study. Also, commercial food products like soups usually contain salt in the 1st sip. Panelists were instructed to start the Time-Intensity rating at a score of 20 (corresponding to a sodium concentration of 0.79 g Na/L). Profile J was included to study the effect of this "salt baseline" and check for adaptation. The concentrations of salt studied were selected to be within the salt concentration range found in commercial soups and to accommodate those panelists who found the upper range of salt in soups to be too salty.

Table 1 hereabouts

The bouillon formulation was provided by Dr J Busch (Unilever, Vlaardingen, The Netherlands) and was prepared by dissolving the following compounds in mineral water (Evian, Danone, France): monosodium glutamate ([142-47-2] 2 g/L; Daesang-Miwon Seoul, Korea), Sucrose ([57-50-1] 1.2 g/L; local supermarket), succinic acid ([110-15-6] 0.15 g/L; Aldrich. Gillingham, UK), disodium 5'-inosinate ([4691-65-0] 0.0275 g/L) and disodium 5'-guanylate ([5550-12-9] 0.027 g/L; both Daesang-Miwon). To achieve the same overall amount of sodium for the same profile in water and bouillon, the amount of salt added to the bouillon base was corrected by the amount of sodium present in MSG, IMP and GMP.

Time – Intensity, Overall Saltiness Score and data analysis

Time-Intensity data were acquired using the Fizz software system (Biosystèmes, France) at an acquisition rate of 1 point/s. Panelists were instructed to start recording as soon as the solution flowed into their mouth by clicking on the score corresponding to the initial salt concentration. Panelists were instructed to hold the tubing tip between their teeth and lips so as to have the tip of the tubing resting on the front of the tongue. This prevented jaw movements and limited tongue movements. Panelists were free to swallow as they wished. At the end of each profile, they were asked to give an Overall Saltiness Score reflecting the saltiness intensity of the whole 15 s profile. For data analysis, due to the presence of several peaks in some profiles, traditional methods of normalizing the TI-curves (Liu & Macfie, 1990; Overbosch et al., 1986) were not suitable. Therefore average curves, maximum intensities (Imax), time to maximum intensity (Tmax), Area Under the Curve (AUC) and Pearson product moment correlation coefficients were calculated using Excel (Microsoft). For each profile, each time-point presented was the average of all the replicates for the same time-point and the Imax, Tmax and AUC values presented, were the average of all the replicates. The Overall Saltiness Scores were subjected to an analysis of variance with four factors (profile, panelist, matrix (i.e. water *vs*. bouillon) and session) and potential interaction between the factors analyzed using SPSS (SPSS Inc, Chicago, USA). Post hoc, where appropriate, a Tukey's HSD test was used to identify which samples were significantly different to the others ($\alpha = 0.05$). A Friedman test followed by a Least Significant Ranked Difference test was also performed on the Overall Saltiness Scores.

Results

Figure 1 records the average Time-Intensity curves for the salt profiles in water and in bouillon while showing the salt delivery profiles programmed into the Dynataste system. The Y axis represents perceived saltiness and the units are a percentage response, based on the sodium standard (3.93 g /L) being used as a 100% saltiness anchor point. The nine salt delivery profiles were designed to deliver different overall amounts of salt or the same overall amount of salt but with different profiles and in water or a bouillon base. Profiles A and B were both designed to deliver 125 mg of sodium while Profiles C through H delivered 90 mg sodium and Profile I delivered 45 mg sodium. The actual overall amounts delivered by Dynataste are recorded in Table 1.

Figure 1 hereabouts

Visual inspection of the averaged TI values of the salt and bouillon curves (Figure 1) showed that Profiles A and B (containing 125 mg sodium) produced maximum sensory intensities around 80 % (relative to the control (100 %) sodium solution of 3.9 g/L) whereas Profiles C to H (90 mg sodium) were fairly consistent with maxima around 60 %. Profile I (45 mg sodium) produced a maximum intensity of around 40%. For the simple profiles A, B and C, the TI curves generally followed the delivery profiles. With profiles D, E and F the effect of delivering different pulse frequencies (1, 2 and 3 s respectively) on salt perception was studied. The average TI curves showed small changes in profile when pulsed salt was delivered but inspection of the individual panelists TI curves were more informative (data not shown). For Profiles F and G (3 s pulses), the TI traces from 7 and 8 out of the 11 panelists respectively followed the peaks and troughs of the delivery profile but the averaged TI curve smoothes out these individual differences. The average T-I curves of profiles F and G for the panelists following the peaks and troughs and those integrating them are presented in Figure 2.

Figure 2 hereabouts

For Profile E (2 s pulses), only 2 out of the 11 panelists' TI traces followed the delivery peaks and troughs, while for Profile D, all the panelists produced smoothed curves with no trace of peaks and troughs occurring.

Panelists also recorded their Overall Saltiness Score for each Profile and the relationship between the TI parameters (Area Under the Curve; AUC) and Maximum Intensity (Imax) was studied by plotting the values (Figure 3).

Figure 3 hereabouts

The graphs showed a linear correlation between Average Overall Saltiness Scores and both Imax and AUC although the correlation for the Imax parameter was better (r^2 0.96) compared to the AUC (r^2 0.87).

The potential impact of pulsed delivery on sensory perception of salt was studied by performing an ANOVA / Tukey's HND test on the Overall Saltiness Scores (Figure 4) and by plotting the Average Overall Saltiness Scores obtained for salt in water and in bouillon against the overall amount of salt delivered (Figure 5).

Figures 4 and 5 hereabouts

The significant parameters affecting the data were delivery profile ($F(8,352) = 30.492$; $p < 0.001$) and assessors ($F(11,352) = 21.878$; $p < 0.001$). The session during which the data were acquired as well as the matrix were not found to have a significant effect on the results (respectively: $F(1,352) = 0.168$; $p = 0.682$ and $F(1,352) = 0.852$; $p = 0.357$). A Profile * Assessor interaction was observed ($F(82,352) = 1.409$; $p = 0.019$) which can be partly explained by the fact that two panelists rated profile C identical or higher than profile A.

Discussion

Time-Intensity Data

<u>Panel Performance</u>

The general shapes of the theoretical Dynataste profiles were correctly followed. Individual assessors were found to be reproducible; however large variations between assessors were noted. These "individual patterns" are a well known feature of Time-Intensity measurements and differences in anatomy, oral manipulation and scaling have been suggested to explain this phenomenon (Lawless & Heymann, 1998). The variability among panelists resulted in moderate to large error bars on the averaged TI traces despite the panelists' training and experience. As a whole, the panel could detect pulses only when the delivery period was around 3 seconds; with a time period less than 3 seconds, most panelists integrated the stimulus into a continuous saltiness response. Quite how the salt receptors across the tongue receive the pulsed delivery of salt is a subject of conjecture. Does each pulse cover the tongue in a "wave" or do the pulses containing different amounts of salt get mixed across the tongue? Can the same sensory saltiness response be elicited by intense stimulation of a few receptors and by lower level stimulation of many receptors? These are issues that require further research studies.

It is interesting to note that when split in two groups (integrating panelists and non-integrating panelists) the AUCs obtained from the integrating panelists were higher than those of the non-integrating panelists for all the profiles and not only for the pulsed profiles. This was reflected in the Overall Saltiness Scores which were consistently higher for the integrating panelists. It is therefore impossible to conclude whether the differences observed between these two groups relate to different perceptions or to different abilities to use the Time-Intensity and single point scales.

Despite the delivery method (time dependent: Dynataste) and the presentation mode (one at a time), the panelists were sensitive to differences corresponding to approximately twice the JND at that salt level (Johansson et al., 1973; Laing et al., 1993) and this also represented the targeted salt reduction (-28%). Hence, decreasing the salt content of a product is likely to be noticed by consumers and illustrates the difficulty in maintaining the original flavor of a food when salt content is decreased.

Saltiness in water and.bouillon

TI traces for saltiness perception in water and in bouillon were plotted for six of the delivery profiles and, in all cases the TI traces in the two matrices were remarkably similar. This suggested that the panelists were focused on saltiness perception in both the salt solution and bouillon samples and that the presence of umami type compounds (glutamate and the nucleotides) in the bouillon did not cause a change in salt perception.

A bouillon system was used as salt solutions were not well-liked by panelists and providing an alternative and more "user friendly" system decreased panel fatigue as well as allowing the opportunity of studying salt perception in a product closer to a real food. The literature contains reports that the ratio of sodium to glutamate affects palatability of the solution (Chi & Chen, 1992; Halpern, 2000; Okiyama & Beauchamp, 1998; Pasin et al., 1989) but the effect of components like glutamate on perceived saltiness are not so well-documented. One report describes a soup system which was formulated with either NaCl or with NaCl and monosodium glutamate and then tested by a sensory panel to determine which formulations were equi-salty (Yamaguchi & Takahashi, 1984). For a salt content close to the ones investigated here, equi-saltiness was achieved for solutions containing the same amount of sodium, suggesting that the glutamate had a minor effect on salt perception as found in the present study. This is consistent with the findings of Tuorila et al. (1990) who reported that, although flavors seemed to contribute to the overall pleasantness of the samples under investigation, their presence did not result in lower NaCl content in ad lib mixing experiments. This supports the idea that MSG or a bouillon flavor can be used to enhance palatability and in that respect plays the same role as salt but does not enhance saltiness in itself.

AUC, Imax, Iend and Overall Saltiness Scores

Both Imax and AUC were positively correlated ($p < 0.001$) with the Overall Saltiness Scores, despite the stimulus being delivered as several peaks over the 15 s duration. This type of relationship between TI data and single sensory scores has been reported previously (Desobry-Bandon & Vickers, 1998; Duizer et al., 1993; Wendin & Hall, 2001). It is generally agreed that, while Time-Intensity measurements yield more information than single score assessments (Lee, 1989), the variation in the Time-Intensity data is often greater (Wendin & Hall, 2001). However, the work cited above related to much simpler delivery profiles than those delivered in this paper and it is interesting to note that the relationships obtained from conventional flavor delivery systems also hold good for the pulsed delivery systems. Comparisons of profiles in which pulse length was identical while final concentration differed, suggested that the final salt concentration did not affect overall salt perception.

Effect of pulsed profiles

The hypothesis was that, if pulsed delivery created a significant change in sensory perception, then the TI profiles for one overall sodium value (e.g. 90 mg) should show a wide spread of sensory responses. However, profiles delivering the same overall amount of sodium were not significantly different from each other. The Overall Saltiness Scores were not affected by a pulsed delivery, but they were strongly correlated ($p < 0.001$) with the overall amount of sodium delivered. This result was confirmed by performing a Friedman test followed by a Least Significant Ranked Difference test on the Overall Saltiness Scores. This suggests that the delivery mechanisms used in this paper did not cause significant changes in sensory perception. However, it is clear that the different profiles produced the maximum intensities at different times. The Tmax values were shorter ($F(8,379) = 18.451$; $p< 0.001$) for profiles which included a return to the baseline. Plateau and short pulses or the 3 s pulse with a high finish profile resulted in longer Tmax values. This difference in delivery timing could potentially affect cross modal interactions between salt and congruent flavorings as the timing of the oral and nasal signals has been shown to affect the perceived intensity of flavors where cross modality occurs (Visschers et al., 2006).

Conclusion

The different delivery profiles did not produce changes in overall sensory perception of salt as measured by single point assessment of the samples or using the AUC parameter extracted from the TI curves. Instead, salt perception was related to the total overall amount of salt delivered in these 15 s delivery profiles, whether delivered as salt solutions or in a bouillon system. Pulsed delivery caused differences in the timing of the maximum perceived salt intensity which may play a role in overall sensory flavor intensity if there are cross modal interactions between saltiness and a savory flavor. Here, saltiness was the sensory parameter measured but, in real foods, salt is not perceived as a single attribute but as part of the total integrated flavor signal and in these situations, there is a possibility that the way salt is delivered may affect the overall flavor.

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Table Legends

Table 1. Salt delivery profiles. All profiles started at 0.79 g Na/l and the table shows the type of delivery (continuous or pulsed) along with the measured delivery of sodium, pulse length, final concentration and the number of replicates in water and bouillon systems. (ND not determined)

Figure legends

Figure 1 Average Time-Intensity curves for the 9 profiles delivered in water (open symbols) and the 6 profiles delivered in bouillon base (filled symbols). The dotted lines represent the profiles programmed in the pumps. The error bars represent +/- 1 standard deviation calculated from the 33 or 66 replicates.

Figure 2 Average Time-Intensity curves for the “integrating panelists” and “non-integrating panelists” (profiles F and G) in water. The error bars represent +/- 1 standard deviation calculated from the 33 replicates.

Figure 3 Relationship between TI parameters, Imax (open symbols) and AUC (filled symbols) and the sensory Overall Saltiness Score for the profiles in water (triangle) and bouillon (circle).

Figure 4 Overall Saltiness Scores (average across all replicates for each profile in water and bouillon ± SD) and overall amount of sodium delivered (diamond symbols). Lower case letters refer to statistically different saltiness scores ($\alpha = 0.05$).

Figure 5 Overall Saltiness Score plotted against overall amount of sodium delivered for profiles delivered in water (filled symbols) and bouillon (open symbols).

References

Abrahams H, Krakauer D & Dallenbach KM (1937) Minor studies from the psychological laboratory of Cornell University LXXXIV Gustatory adaptation to salt. American Journal of Psychology, 49, 462-469.

Angus F (2007) Dietary salt intake: sources and targets for reduction. In: Reducing salt in foods. Practical strategies. Woodhead Publishing Limited, Cambridge.

Bujas Z, Ajdukovic D, Szabo S, Mayer D & Vodanovic M (1995) Central Processes in Gustatory Adaptation. Physiology & Behavior, 57(5), 875-880.

Chi SP & Chen TC (1992) Predicting Optimum Monosodium Glutamate and Sodium-Chloride Concentrations in Chicken Broth as Affected by Spice Addition. Journal of Food Processing and Preservation, 16(5), 313-326.

Desobry-Bandon S & Vickers Z (1998) Cohesiveness of mass evaluation by time-intensity and single value measurements. Journal of Food Science, 63(1), 174-176.

Dubois GE & Tsau J (1992) Low sodium salt composition suitable as table salt - comprises sodium chloride, non-gritty bulking agent and binder. Patent no US5098724-A.

Duizer LM, Gullett EA & Findlay CJ (1993) Time-Intensity Methodology for Beef Tenderness Perception. Journal of Food Science, 58(5), 943-947.

Ganzevles PGJ & Kroeze JHA (1987) Cross-Adaptation in Taste Measured with a Filter-Paper Method. Chemical Senses, 12(2), 341-353.

Halpern BP (2000) Glutamate and the flavor of foods. Journal of Nutrition, 130(4), 910S-914S.

Halpern BP & Meiselman HL (1980) Taste Psychophysics Based on a Simulation of Human Drinking. Chemical Senses, 5(4), 279-294.

Hort J & Hollowood TA (2004) Controlled continuous flow delivery system for investigating taste-aroma interactions. Journal of Agricultural and Food Chemistry, 52(15), 4834-4843.

Johansson B, Drake B, Pangborn RM, Barylkop N & Koster E (1973) Difference Taste Thresholds for Sodium-Chloride among Young Adults - Interlaboratory Study. Journal of Food Science, 38(3), 524-527.

Laing DG, Prescott J, Bell GA, Gillmore R, James C, Best DJ, Allen S, Yoshida M & Yamazaki K (1993) A Cross-Cultural-Study of Taste Discrimination with Australians and Japanese. Chemical Senses, 18(2), 161-168.

Lawless HT & Heymann H (1998) Sensory Evaluation of Food: Principles and Practice. Kluwer Academic/Plenium Publishers, New York, USA.

Lee WE (1989) Single-point versus time-intensity sensory measurements: an informational entropy analysis. The journal of sensory studies, 4(1), 19-30.

Liu YH & Macfie HJH (1990) Methods for Averaging Time-Intensity Curves. Chemical Senses, 15(4), 471-484.
McBurney DH (1976) Temporal Properties of Human Taste System. Sensory Processes, 1(2), 150-162.
Meiselman HL & Buffington C (1980) Effects of Filter-Paper Stimulus Application on Gustatory Adaptation. Chemical Senses, 5(4), 273-277.
Meiselman HL & Halpern BP (1973) Enhancement of Taste Intensity through Pulsatile Stimulation. Physiology & Behavior, 11(5), 713-716.
Moskowitz HR (1978) Taste and food technology: acceptability, aesthetics, and preference. In: Handbook of Perception VIA Tasting and smelling. Academic Press, New York.
Neyraud E, Prinz J & Dransfield E (2003) NaCl and sugar release, salivation and taste during mastication of salted chewing gum. Physiology & Behavior, 79(4-5), 731-737.
Okiyama A & Beauchamp GK (1998) Taste dimensions of monosodium glutamate (MSG) in a food system: Role of glutamate in young American subjects. Physiology & Behavior, 65(1), 177-181.
Overbosch P, Vandenenden JC & Keur BM (1986) An Improved Method for Measuring Perceived Intensity Time Relationships in Human Taste and Smell. Chemical Senses, 11(3), 331-338.
Pasin G, Omahony M, York G, Weitzel B, Gabriel L & Zeidler G (1989) Replacement of Sodium-Chloride by Modified Potassium-Chloride (Cocrystalized Disodium-5'-Inosinate and Disodium-5'-Guanylate with Potassium-Chloride) in Fresh Pork Sausages - Acceptability Testing Using Signal-Detection Measures. Journal of Food Science, 54(3), 553-555.
Theunissen MJM & Kroeze JHA (1996) Mouth movements diminish taste adaptation, but rate of mouth movement does not affect adaptation. Chemical Senses, 21(5), 545-551.
Theunissen MJM, Polet IA, Kroeze JHA & Schifferstein HNJ (2000) Taste adaptation during the eating of sweetened yogurt. Appetite, 34(1), 21-27.
Tuorila H, Hellemann U & Matuszewska I (1990) Can Sodium Contents of Foods Be Reduced by Adding Flavors - Studies with Beef Broth. Physiology & Behavior, 47(4), 709-712.
UK Food Standards Agency (2008) UK industry commitments to salt reduction. Available at: http://www.food.gov.uk/multimedia/spreadsheets/saltcommitmentsum.xls. Accessed 22/12/2008
Visschers RW, Jacobs MA, Frasnelli J, Hummel T, Burgering M & Boelrijk AEM (2006) Cross-Modality of Texture and Aroma Perception Is Independent of Orthonasal or Retronasal Stimulation. Journal of Agricultural and Food Chemistry, 54(15), 5509-5515.
Wendin K & Hall G (2001) Influences of fat, thickener and emulsifier contents on salad dressing: Static and dynamic sensory and rheological analyses. Lebensmittel-Wissenschaft Und-Technologie-Food Science and Technology, 34(4), 222-233.
Yamaguchi S & Takahashi C (1984) Interactions of Monosodium Glutamate and Sodium-Chloride on Saltiness and Palatability of a Clear Soup. Journal of Food Science, 49(1), 82-85.